MULTIFUNCTIONAL STRUCTURAL ELECTRONICS PACKAGING

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Final Report

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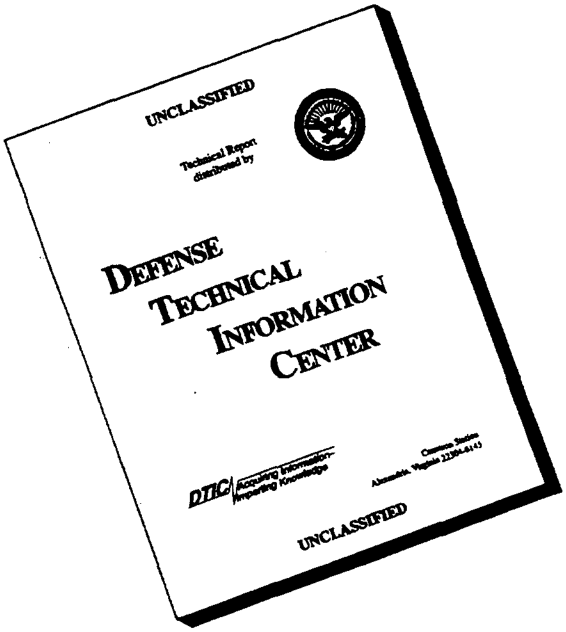

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13. Supplementary Notes

14. Abstract This project demonstrated the feasibility of developing a highly integrated multifunctional component that would enable Multichip Modules (MCMs) to be mounted directly to the surface of a spacecraft panel. The benefits of this concept over conventional black box technology are: >90% weight savings, >90% volume savings, >70% surface area savings, better thermal path for waste heat rejection, and elimination of extensive amounts of cabling. This concept for packaging is essential if small spacecraft are going to be developed and deployed. 500 kgs spacecraft that require high levels of electronic data processing cannot be developed using conventional black box technology; the new millenium spacecraft require this technology to achieve the mission goals. The results demonstrated that a multifunctional component that has the correct CTE, high thermal conductivity, high stiffness, and lightweight can be manufactured.

15. Subject Terms Multifunctional, Composites, Electronics, Packaging, Lightweight, Constraining Core

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EXECUTIVE SUMMARY

Packaging of electronic components in spacecraft requires a large amount of weight and volume. Conventional packaging of electronics is accomplished with "black boxes" containing ~ 10-12 printed wiring boards attached to the inside wall of the spacecraft. Each black box weighs approximately 35 lbs and requires up to 1000 in^3 of internal volume. For smallsat spacecraft, where internal volume is limited, conventional packaging black box is not an attractive option. Emerging technologies such as multichip modules (MCMs) and lightweight, high thermal conductivity composite materials enable higher density, lower weight concepts for packaging electronics within the internal volume of a spacecraft.

The objective of this project was to demonstrate the feasibility of developing a multifunctional component that can serve as the spacecraft structure and as a printed wiring board for MCMs. The multifunctional component is illustrated in Figure 1. The component is a metal foam core sandwich structure which has a printed wiring board as an inner facesheet and carbon-carbon composite as an outer facesheet. Three dimensional MCMs are surface mounted to the inner facesheet as a replacement for black boxes. In the Phase I SBIR project the feasibility of developing such a component was investigated by addressing the following issues:

- Thermal coefficient of expansion matching of the surface mount MCMs and the structure
- Stresses in printed circuits, through-holes, and lead bonds
- Achievement of heat transfer characteristics to minimize temperature rise in electronic components
- Compatibility of components with the fabrication environments
- Achievement of electrical isolation whenever needed

The multifunctional component is achieved by using multiple three dimensional (3D) MCMs to replace the data processing capability of a black box. Four 3D MCMs are expected to provide the processing capability needed to replace one black box. The MCMs are surface mounted to the inner facesheet of a structural component that is a printed circuit board reinforced with 2 layers of carbon composite material. The carbon composite material constrains the thermal expansion of the printed circuit board, provides stiffness for the facesheet and provides thermal conductivity for heat dissipation. An outer facesheet of high conductivity carbon-carbon material is used to radiate heat to deep space. The two facesheets are separated by a lightweight metal core material.

The Phase I project successfully demonstrated the feasibility of the concept and it generated excellent results that justify the continuation of the development of a multifunctional component. Highlights of the accomplishments are listed as follows:

- Demonstrated a CTE for the multifunctional component that was closely matched to MCM component materials (4.0 to 5.0 ppm/°C)

- Physical packaging characteristics are significantly improved over a black box approach
  - > 90% weight savings
  - > 90% volume savings
  - > 70% reduction in surface area
  - Elimination of major thermal resistance paths
  - Elimination of extensive amounts of cables/wire harnesses

- Demonstrated processibility of kevlar/polycyanate and glass/polyimide PWBs with carbon composite layers

- Fabricated and tested two functional, multilayered operational PWBs

- Successfully fabricated two 6" x 6" multifunctional demonstrator components
  - Kevlar/polycyanate with carbon composite layers on a SiC/Al foam core
  - Glass/polyimide with carbon composite layers on an Al foam core
  - Both components had C-C facesheets

- Demonstrated heat dissipation capability at 5 w/in^2 and 10 w/in^2

Based on the results of this Phase I project, it is evident that this concept for electronics packaging has benefits and is worthy of further development. Recommendations for future research and development are listed as follows:

- Use aluminum honeycomb core with the facesheets that were developed
- Continue evaluation of kevlar-glass/polycyanate to determine potential benefits over glass/polyimide
- Fabricate a 6" x 6" operational multifunctional processor component (populated with components)
- Conduct qualification type environmental testing

1.0 INTRODUCTION

Future smallsat missions require sophisticated payloads and instrumentation that need to be packaged in a weight and volume constrained design. A high degree of signal processing performance coupled with less physical volume requires innovative electronics packaging concepts that achieve smaller area and volume, are lightweight, and are highly reliable. This project is the development of a multifunctional structural electronics packaging approach that combines advanced electronics packaging with lightweight structures and thermal management technology. This involves the development of an integrated structural electronics panel that has printed circuits integrally laminated into the structural facesheets/panels. AMT, Inc. has developed a design of a novel packaging approach that will reduce the weight and the internal volume of a spacecraft. The primary constituents of this concept are a sandwich structure comprised of: 1) integrated circuits (ICs)/chip carriers or chip-on-film mounted on a multilayered Printed Wiring Board (PWB) 2) carbon fiber composite constraining core layers within the PWB itself, or carbon fiber composite internal facesheet; 3) a sandwich structure core that matches the coefficient of thermal expansion (CTE) of the electronics components; and, 4) an external radiating facesheet. An illustration of the concept is given in Figure 1.

In concept, this integration of electronic components into a load bearing structure applies to any application where minimizing weight and volume are of major concern. This includes, for example, spacecraft, aircraft, automobiles, and portable consumer electronics. This Phase I project focused on spacecraft application and, in particular smallsat application. Phillips Laboratory VTE was the program manager for this project; however, since this technology involves both electronics and structural functions, both the VTE and VTS organizations provided input into the direction of this project. Lockheed-Martin participated as a subcontractor and is currently investigating complementary technology for VTS in a separately funded project.

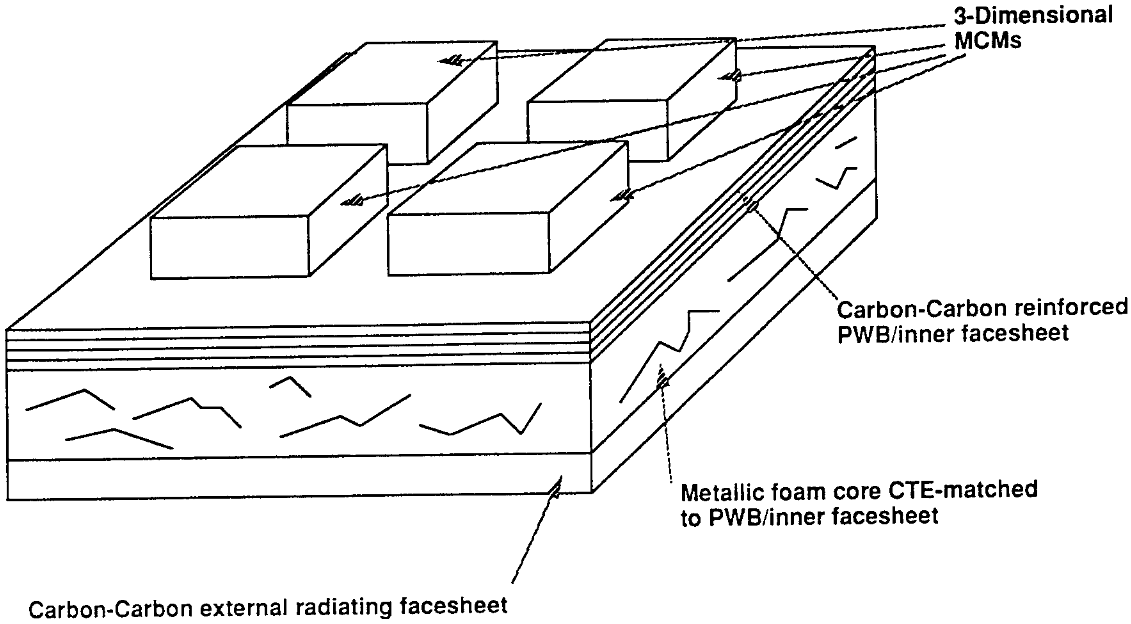


Figure 1. Multifunctional Concept

2.0 PHASE I OBJECTIVES

This Phase I project demonstrated the feasibility of producing a multifunctional structural electronics packaging system for smallsat utilization. The following issues were considered in this project and Table 1 summarizes the results that were obtained in Phase I.

- Can the CTE of the structure be matched to the printed circuits and IC components?

- Is the stiffness of the combined structure sufficient to minimize or eliminate the stresses in the printed circuits, the through holes, and component lead bonds?

- Are the heat transfer characteristics of the concept sufficient to meet temperature requirements for the ICs?

- Can the materials survive the processing environments involved with the fabrication of printed circuit boards?

- Can electrical isolation be achieved wherever it is needed?

These challenges were addressed by analytical design studies and actual prototype testing.

Table 1. Demonstration of Feasibility

Key Issues	Phase I Relevant Results
• Matching of CTE between the internal facesheet/PWB material and the IC components	Glass/Polyimide PWBs and kevlar/glass/polycyanate hybrid PWBs with embedded carbon layers were fabricated and the CTE was 3.1 to 4.8 (polyimide) and 4.7 to 4.6 (kevlar-glass). This is a very close match to Al_2O_3.
• Adequacy of the stiffness of the internal facesheet/PWB material	The glass/polyimide PWB had a measured modulus of 5.5 (tensile) and 7.6 (compressive) and the kevlar-glass hybrid PWB had a modulus of 9.12 (tensile) and 7.6 (compressive). This is more than twice the value of a typical PWB. Also with the board mounted on a sandwich structure it is much more rigid than an unsupported clamp mounted PWB.
• The heat transfer characteristics to meet temperature requirements for ICs	The internal facesheets for the glass/polyimide and kevlar-glass hybrid had thermal conductivities of 78 W/M-K and 56 W/M-K respectively. Also, a simulation of high power output devices mounted to a 6 in. x 6 in. sandwich panel demonstrated a peak temperature of 90°C at a 60 W/in^2 flux. This is below the junction temperatures specified in spacecraft design.
• Processing environments	Both internal facesheet materials were used to fabricate a simple, functional 3D multilayered circuit. These materials were exposed to all of the typical PWB processing environments and survived.

3.0 PHASE I RESULTS

The Phase I project is illustrated in Figure 2. Task 1 is a definition of spacecraft requirements and this was supplied by Lockheed-Martin, Denver, CO. They supplied requirements based on their on-going NASA Small Spacecraft Technology Initiative (SSTI). Task 2 developed preliminary designs of the sandwich structure. Internal and external facesheet materials were designed/analyzed and trades were made to determine the best configuration for CTE matching and thermal conductivity. In Task 3, facesheet panels including PWBs and carbon-carbon were produced, core materials of aluminum and SiC/Al were fabricated and 6 in. x 6 in. subassemblies were tested in Task 4. Tests on internal PWB facesheet materials included CTE, thermal conductivity, tension, and compression. In Task 5, strip heaters were attached to 6 in. x 6 in. sandwich core structures and the simulated temperatures were equivalent to a set of MCMs that could replace the computing capability of a typical black box with twelve PWBs. The Phase II Plan was eliminated from the scope of work when AMT was notified in June that a Phase II proposal would not be selected. AMT, Inc. will continue the development of this novel concept with in-house research funds.

3.1 TASK 1 SPACECRAFT REQUIREMENTS

Lockheed-Martin provided requirements to AMT, Inc. in three separate categories as follows:

Structural/Mechanical/Thermal

- First natural frequency ≥ 20Hz
- High thermal conductivity composite panels
- Integral structure and electronic functions
- Accommodate post-potted inserts/self aligning nut plates

Environments

- Static/quasistatic loads
- Acoustics
- Vibration
- Shock

Thermal (varies for each component)

- Temp limits
- Heat loads

These requirements were used as a qualitative guide for the concept development. Typical temperatures based on orbital mechanics are illustrated in Table 2.

Table 2. Spacecraft Temperature Requirements

Orbital Environment 475 km Beta Angle Range: 2.6 in. to 17.4 in.	**Spacecraft Attitude** Normal Ops + Z Nadir - Pointing Safe Mode - Z - Sun Pointing	
Component	**Temp. Limits (predicts)**	**Heat Loads (predicts)**
Battery (peak)	-5°C to 127°C	47.9 W Peak (0.33 W/Sq. In.)
Battery (orbital average)	-3°C to 15°C (1 battery alive)	17.9 W-15°C to 45°C
Power Module	-15°C to 45°C	40.3W (0.41W/Sq.In.)
C&DH Module	-15°C - 45°C	30.0 W (0.55 W/Sq.In.)
ADACS Computer	-15°C to 35°C	5.7W
Comm Components	-15°C to 35°C	15.6W
Propulsion Components	10°C to 40°C	1.8W
Solar Array Panel	-110°C to 120°C	N/A
SA Drive (motor driven)	-30°C to 70°C	3W
SA Drive (SMA)	-10°C to 45°C	3W
Mission Phase		**Heat Loads (inside bus)**
Nom. Mission (hot case)	--	187 W (w/o battery)
Prim. Wing Only (cold case)	--	121 W
Safe Mode (cold case)	--	121 W

In this Phase I project AMT investigated heat loads that were much higher than shown above because this concept will enable high power density MCMs ($5W/In^2$) to be mounted to the surface.

Lockheed-Martin also provided an illustration of their structural/electronics integration configurations. This is illustrated in Figure 2.

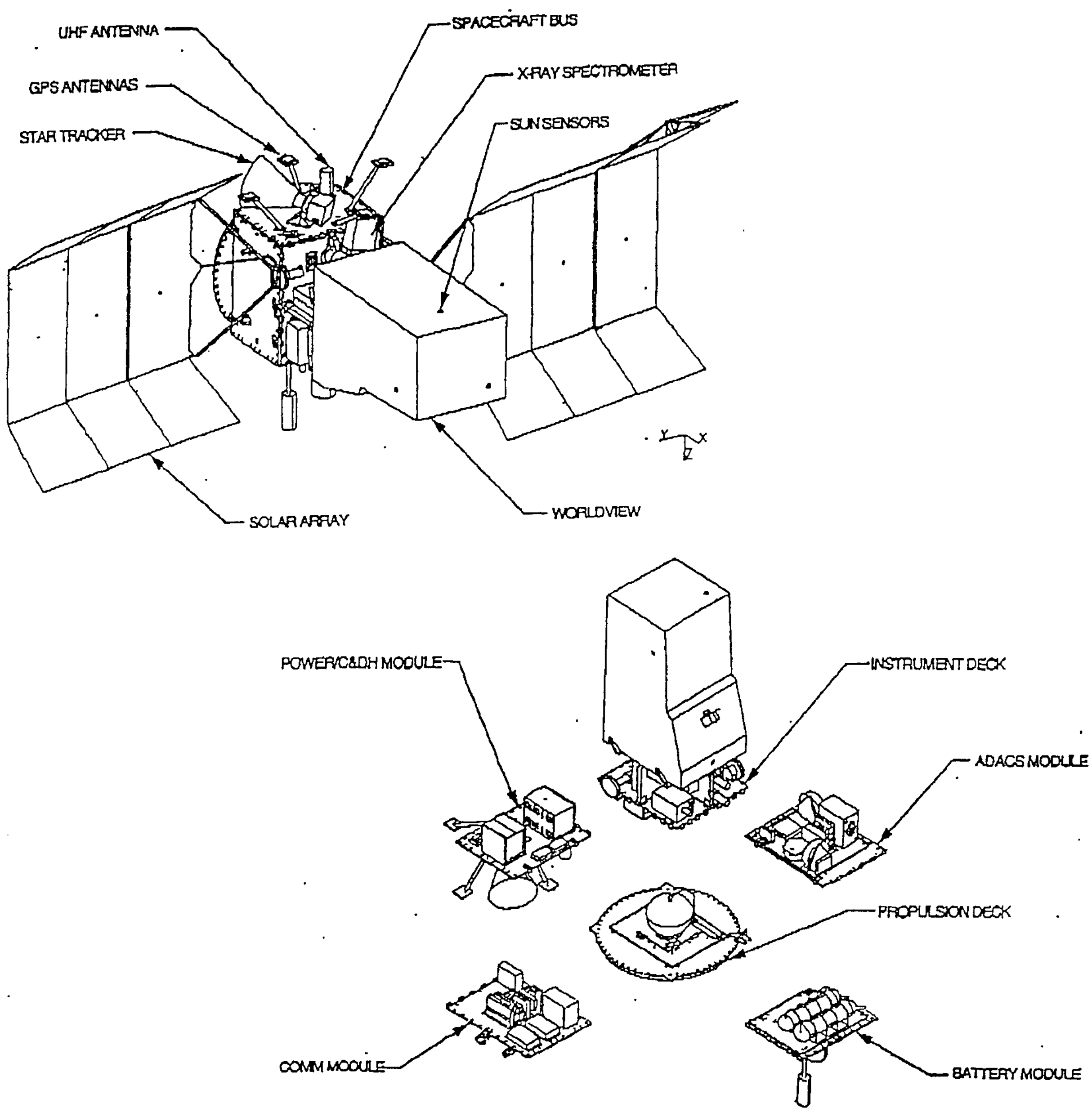
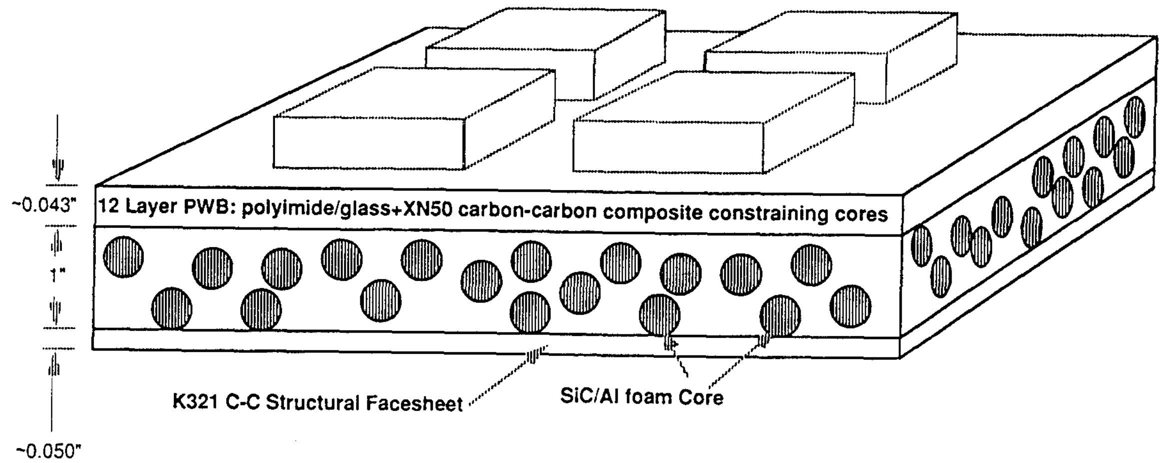


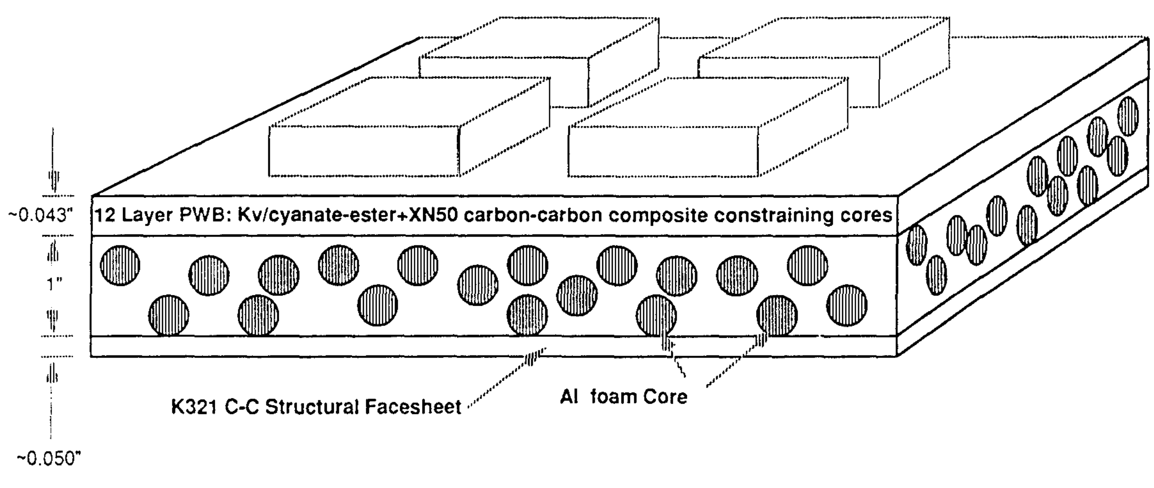
Figure 2. Spacecraft Configurations

3.2 TASK 2 - PRELIMINARY DESIGN/ANALYSIS

Several different configurations of internal and external facesheets mounted on various cores were evaluated analytically. From the initial evaluation, two primary concepts, as shown in Figures 3a and 3b, were selected and evaluated in further detail. Concept A is a sandwich structure with an inner facesheet panel of 12-layer PWB made from polyimide/glass with XN50 carbon-carbon (C-C) constraining material embedded as electrical layers. The core of the sandwich is SiC/Al metal foam or Al metal foam and the outer facesheet is high conductivity K321 C-C. The inner facesheet panel would have printed circuit for mounting electronic components such as multichip modules (MCMs). Concept B is similar to Concept A with the exception of the inner facesheet layer. This layer is a kevlar-glass/polycyanate 12 layer PWB with C-C constraining material embedded for dimensional control.



a. Preliminary Design



b. Preliminary Design

Figure 3. Multifunctional Component Preliminary Designs

The 12 layer PWB inner facesheet design is shown in Figure 4. Each polyimide/glass or kevlar/cyanate ester layer represents a conductive layer of the PWB, i.e. a printed circuit exists on the face of each layer. XN50 is used between layers 2 and 4 and between layers 9 and 11. The constraining layers are ~.009 in. in thickness and they provide dimensional control, thermal conductivity and stiffness for the board. Analyses of the two concepts predicted the CTE of the sandwich structures constituents before assembly as well as the values of the constituent elements that made up the structure. These results are given in Table 3 (Test results are given for comparison).

Table 3. Properties of Multifunctional Component and Subelements

Description	Properties			
		(CTE) PPM/°C	E (MSI)	K (W/M-K)
Kevlar - Glass/ Cyanate Ester PWB	Calc. (Measured)	5.04 (4.7)	2.82 (9.12)	-- 56
E-Glass/ Polyimide PWB	Calc. (Measured)	9.11 (4.8)	3.4 (5.6)	-- 78
Al Foam 10% Dense	Calc. (Measured)	22.68 N/A	.01 N/A	N/A
SiC/Al Foam 15% Dense	Calc. (Measured)	25.3 N/A	.05	N/A
1:1 K321 C-C	Calc. (Measured)	-.635 (-.800)	--- 22	-- 217
Kevlar-Glass/ Cyanate Ester SiC/Al Foam	Calc. (Measured)	4.3 (6.7)	N/A	N/A
E-Glass/ Polyimide Al Foam	Calc. (Measured)	4.62 (7.8)	N/A	N/A

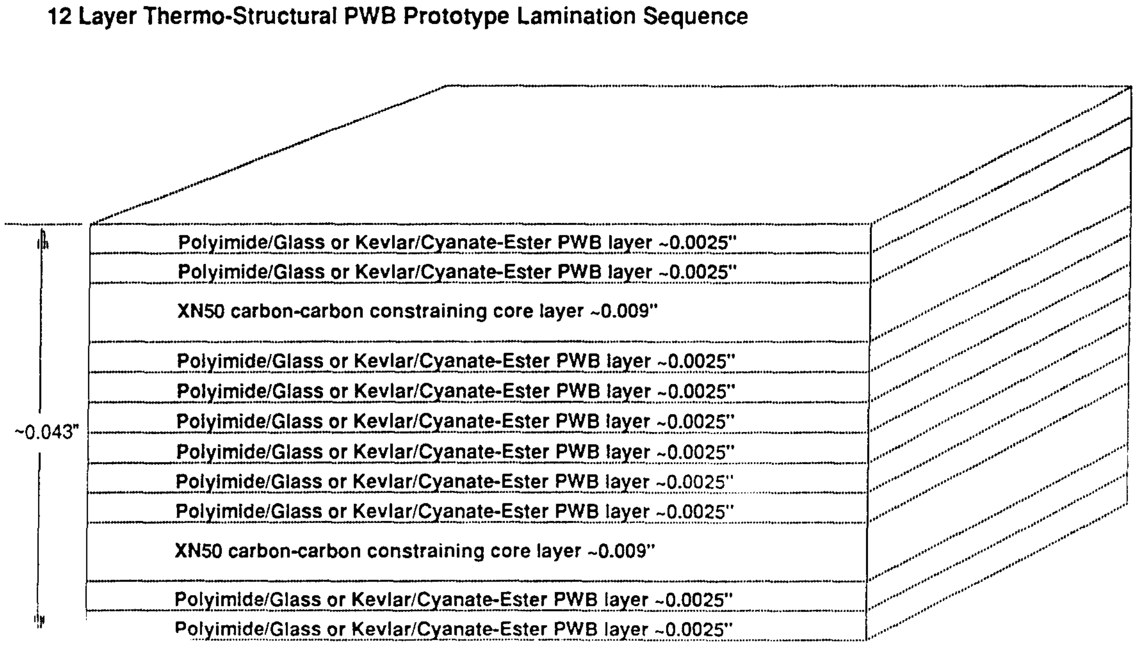


Figure 4. Multifunctional Structural Electronics Packaging Project

The CTE values of the multifunctional subelements (i.e. facesheets) and the sandwich structures are very good and fall within a range that most packaging engineers try to achieve when mounting components on boards. The conductivity values are more than an order of magnitude higher than typical glass/polyimide PWBs which will help spread heat and isothermalize the internal facesheet if components were surface mounted onto the inner wall of the spacecraft. The other interesting finding of these results is that the low value of CTE measured by the two inner facesheet materials will enable these PWBs to be used by themselves or with an ultralight Honeycomb core material and still achieve a matching CTE for electronic components.

3.3 TASK 3 - FABRICATION

The Phase I project produced the following items (Refer to Table 4)

- 2 functional PWBs that contained 3 layers of circuitry
- 4 multifunctional inner facesheet components (2 kevlar-glass and 2 polyimide glass) with C-C constraining cores
- 2 multifunctional sandwich structure prototypes with C-C facesheets on one surface and a simulated multifunctional PWB on the other surface.

The fabrication steps and the subelements that were fabricated to make all of the various components are illustrated in Figure 5 and the final components that were produced are shown in Figure 6. The first step in producing the test articles is fabrication of constituent products. Polyimide/glass and cyanate ester/kevlar-glass prepreg are used to fabricate the multifunctional PWBs. The multifunctional PWB was produced as 3-layer PWBs with functional electrical capability and as a 12-layer laminated stack of materials that simulates the structural and thermal characteristics of the inner facesheet of the multifunctional component. Both the three-layer PWBs and the 12 layer simulated PWBs have XN 50 C-C cores embedded within the laminate. The 3 layer PWBs use one layer of C-C and the 12 layer simulated PWBs use two layers of C-C. There were two 3-layer PWBs produced and these were tested for electrical performance. A total of four 12-layer simulated PWBs were produced and two of the 12-layer simulated PWBs were cut into test articles to measure the mechanical and thermal properties. The other two 12 layer simulated PWBs were used in the assembly of the multifunctional components. The multifunctional components are assembled using the Al or SiC/Al foam core, the 12 layer simulated PWB and the K321 C-C facesheet panels. A total of two multifunctional components were produced.

The three layered PWBs were tested for electrical continuity and for PWB quality. Fabricating the kevlar-glass boards required several iterations, however 2 boards were eventually produced. An example of the kevlar-glass PWB is shown in Figure 7. Figure 8 shows the glass/polyimide PWB. This material required fewer iterations than the kevlar-glass/cyanate ester. The ease of processing for this PWB is attributed to the manufacturing experience of glass/polyimide. The kevlar-glass/cyanate ester PWBs should have lower residual stresses and better resistance to delamination under thermal cycling. An example of the aluminum foam core is shown in Figure 9. This core provided a very lightweight rigid structure; the SiC/Al core did not have the same level of quality as the Al core. In

previous projects AMT has acquired better quality SiC/Al core, however, it was not available from this source and therefore an alternate company (Alcan) produced it.

A photograph of the kevlar-glass/cyanate ester, SiC/Al core structure is shown in Figure 10. Figure 11 shows the glass/polyimide Al core structure that was fabricated. Both structures have K321 C-C for the outer facesheets.

Table 4. Description of Test Articles Fabricated

Item No.	Description	Dimensions	Quantity
1.	3-layer glass/polyimide printed wiring board with one XN50 C-C constraining core; daisy chain circuit with isolated holes tied to the carbon layer	6 in. x 6 in. x .020 in.	1
2.	3-layer kevlar-glass/cyanate ester printed wiring board with one XN50 C-C constraining core; daisy chain circuit with isolated holes tied to carbon layer	6 in. x 6 in. x .020 in.	1
3.	Simulated, non-functional 12-layer glass/polyimide printed wiring boards with two XN50 C-C constraining cores	6 in. x 6 in. x .043 in.	2
4.	Simulated, non-functional 12-layer glass-kevlar/cyanate ester printed wiring board with C-C constraining cores	6 in. x 6 in. x .043 in.	2
5.	K321 panels	6 in. x 6 in. x .043 in.	2
6.	Aluminum foam core	6 in. x 6 in. x 1 in.	1
7.	Silicon carbide/aluminum (SiC/Al) foam core	6 in. x 6 in. x 1 in.	1
8.	Multifunctional component assembled from glass/polyimide PWB (Item 3), aluminum foam core (Item 6) and K321 C-C panels (Item 5)	6 in. x 6 in. x 1.086 in.	1
9.	Multifunctional component assembled from kevlar-glass cyanate ester PWB (Item 4), SiC/Al foam core (Item 7) and K321 C-C panels (Item 5)	6 in. x 6 in. x 1.086 in.	1

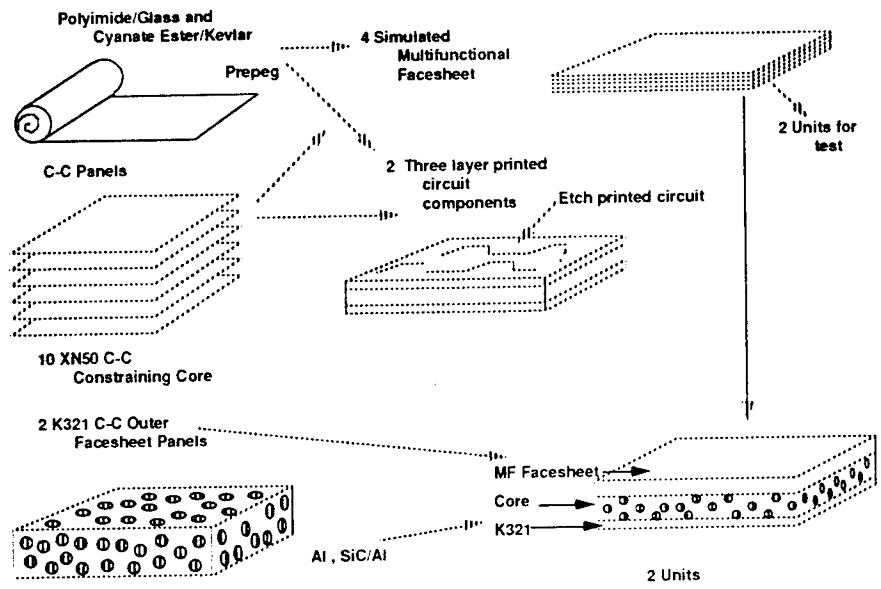


Figure 5. Subelement Fabrication Steps

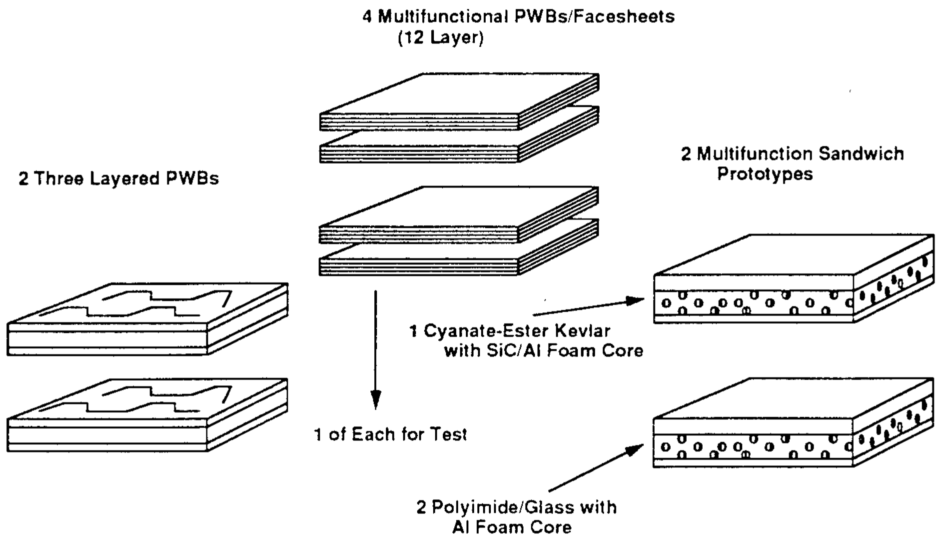


Figure 6. Test Articles Fabricated

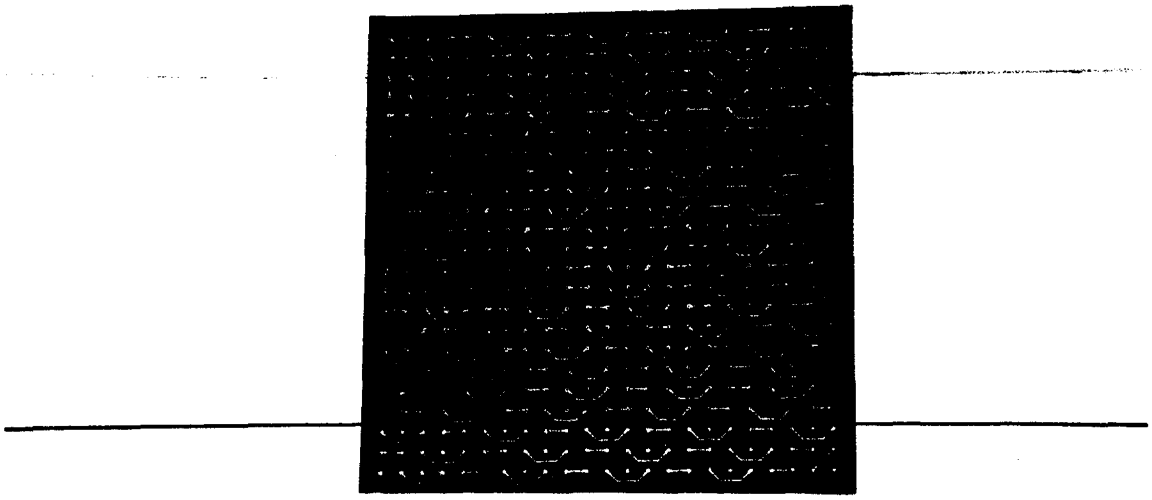


Figure 7. Kevlar-Glass/Cyanate Ester PWB with Carbon Core

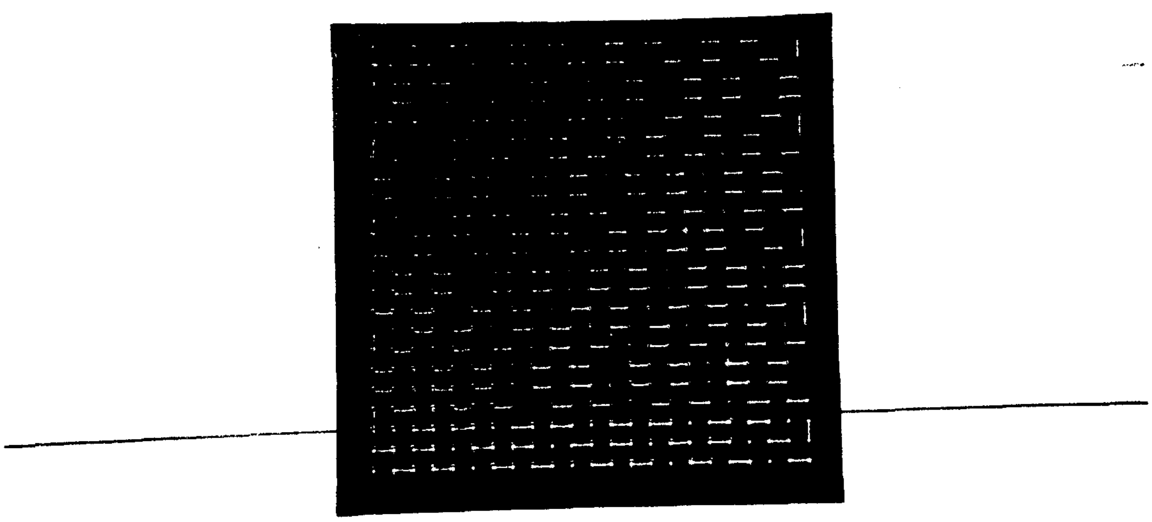


Figure 8. Glass/Polyimide PWB

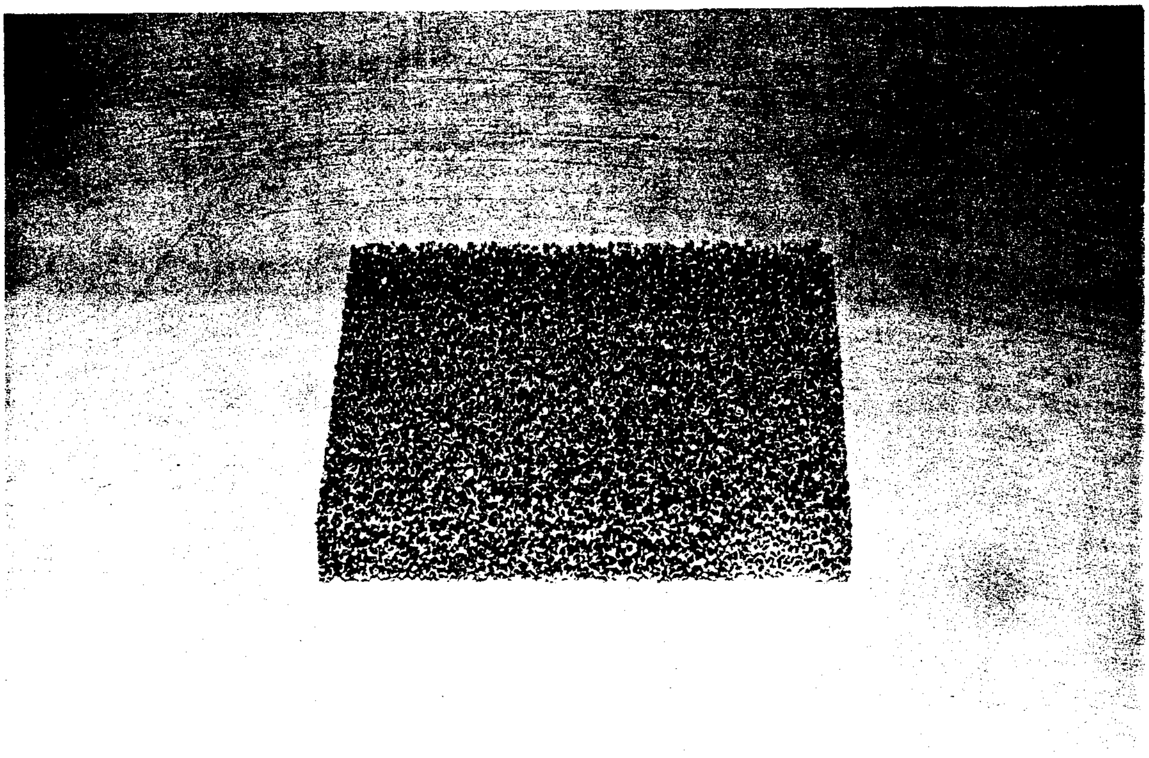


Figure 9. Aluminum Foam Core

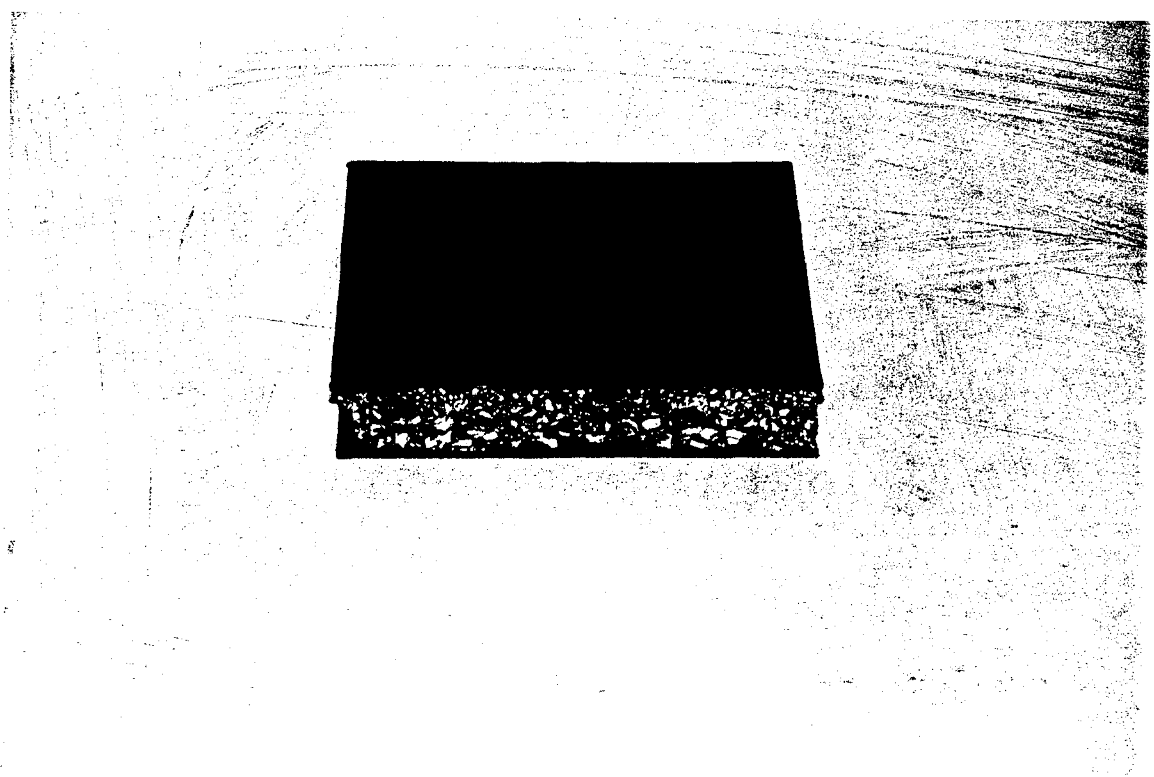


Figure 10. Kevlar-Glass/Cyanate Ester SiC/Al Core Structure

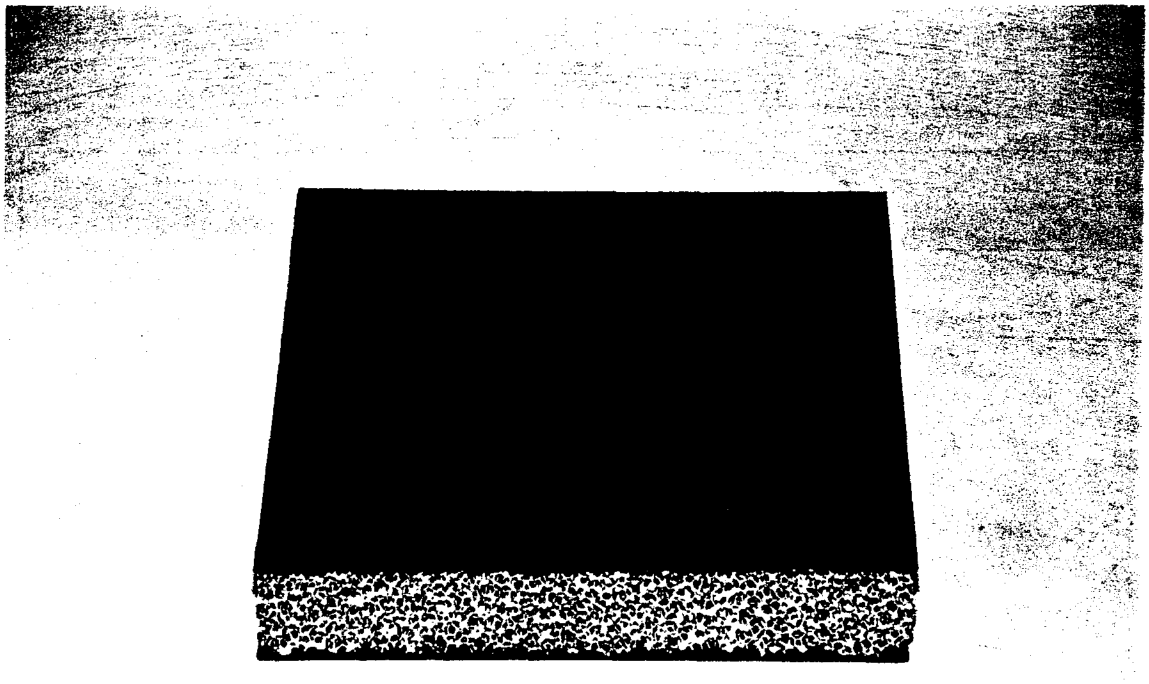


Figure 11 - Glass Polyimide-Al Foam Core Structure

All items that were planned to be fabricated were produced successfully. Both concepts for sandwich structure are feasible and further testing and evaluation would be needed to selected one over another.

3.4 TASK 4 - TESTING

A test plan was devised to investigate various aspects of the multifunctional component. This test plan is described in Table 5. The functional three layer boards were used to demonstrate that the materials could be fabricated into PWBs and that electrical continuity could be achieved and maintained throughout the various processing steps. The 12 layer facesheet components were used to measure structural properties of the PWB facesheets. All in-plane properties were measured in both directions. The assembled multifunctional components were measured for CTE and a thermal performance simulation

of high power density components was also conducted. This latter test is discussed in Paragraph 3.5.

3.4.1 Three Layer Function PWBs

The three layer functional PWBs were fabricated and tested at CEDKO electronics. Fabrication involves copper lamination, chemical photo etching, hole drilling and plating. The PWBs were fabricated and continuity checks were made on the electrical circuit. Both types of PWB materials (glass/polyimide and kevlar-glass/cyanate ester) resulted in satisfactory quality and performance. There were no apparent delaminations after 200°C solder reflow, all holes were of high quality with electrical tie into the carbon layers and the peel strength of the copper was estimated to be greater than 15 KSI based on a standard PWB QC test. The electrical resistivity of the C-C is high enough to be used for electrical magnetic interference shielding, however, it is excessive for grounding of high speed digital electronics. Improvements can be made using copper plating however this adds weight and may affect the processing approach that AMT is using to manufacture these PWBs.

3.4.2 Multilayered Board Materials

The 12 layer PWBs were tested to determine the properties that a structural design engineer could expect if the PWB were used as a facesheet material. Test results are summarized in Table 6.

Table 5. Test Plan

	# of Tests	Test Type	Direction
3-Layer Boards		Continuity	
		Proof of Processing Proof	
2 Simulated 12-Layer Facesheets	3	Tensile	11
	2	Tensile	22
	1	Tensile	33
	3	Compression	11
	1	Compression	22
	1	Conductivity	11
	1	Conductivity	33
	1	CTE	11
	1	CTE	22
2 Multifunction Components	1	CTE	11
	1	CTE	22
	1	Temp Validation	

Table 6. Summary of Test Results for PWB Materials

Properties	Kevlar-Glass/Cyanate PWB	Glass/Polyimide PWB
Tensile Warp (11)		
UTS (KSI)	43.4	23.2
Modulus (MSI)	9.12	5.42
Tensile Fill (22)		
UTS (KSI)	33.8	17.86
Modulus (MSI)	9.83	5.47
Compression Warp (11)		
UTS (KSI)	24.76	26.88
Modulus (MSI)	9.42	7.62
Compression Fill (22)	25.04	28.76
UTS (KSI)		
Modulus (MSI)	8.80	7.98
CTE Warp (11) (PPM/°C)	4.7	4.8
CTE Fill (22) (PPM/°C)	4.6	4.3
(W/M-K)		
Conductivity Warp (11)	57.6	75.2
(W/M-K)		
Conductivity Fill (22)	54.3	71.8

3.5 TASK 5 - PERFORMANCE VALIDATION

This task is intended to demonstrate or validate the performance benefits of this multifunctional concept over conventional black box packaging approaches. The tests/analyses that were made were for the physical characteristics, i.e. surface area (footprint), volume and weight; the facesheet panels we retested for temperature values and temperature distribution when subjected to high power density levels. To conduct this comparison it was assumed that 4 highly integrated multichip modules (MCMs) could replace a black box containing 12 printed wiring boards. The MCMs would be 2 in. x 2 in. x 1 in. and would be distributed evenly over a 5 in. x 5 in. area. An equivalent black box was assumed to have dimensions of 12.31 in. x 7.75 in. x 9.7 in.. Figures 12 and 13 illustrate the volume and surface area comparisons that were made respectively; Lockheed Martin provided the physical data for the black box and PL/VTEE supplied the information for the MCMs. Table 7 summarizes the physical comparison of weight, volume and surface area for conventional black box technology and for a multifunctional component that would utilize MCMs.

Table 7. Physical Comparison

Evaluation Parameter	Multifunction Component	Conventional Black Box	% Reduction
Weight	2.65 lbs	38.2 lbs	93.1
Volume	25.0 in^3	925.3 in^3	97.3
Area	25.0 in^2	95.4 in^2	73.8

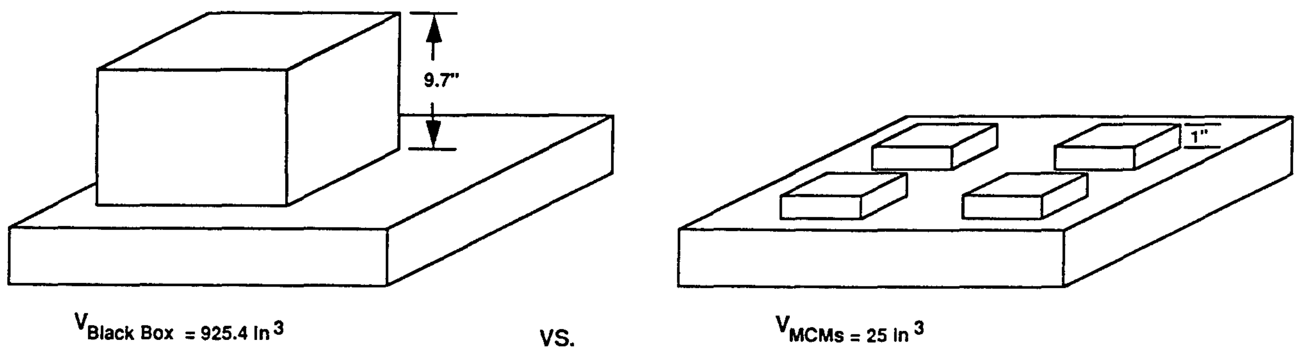


Figure 12. Volume

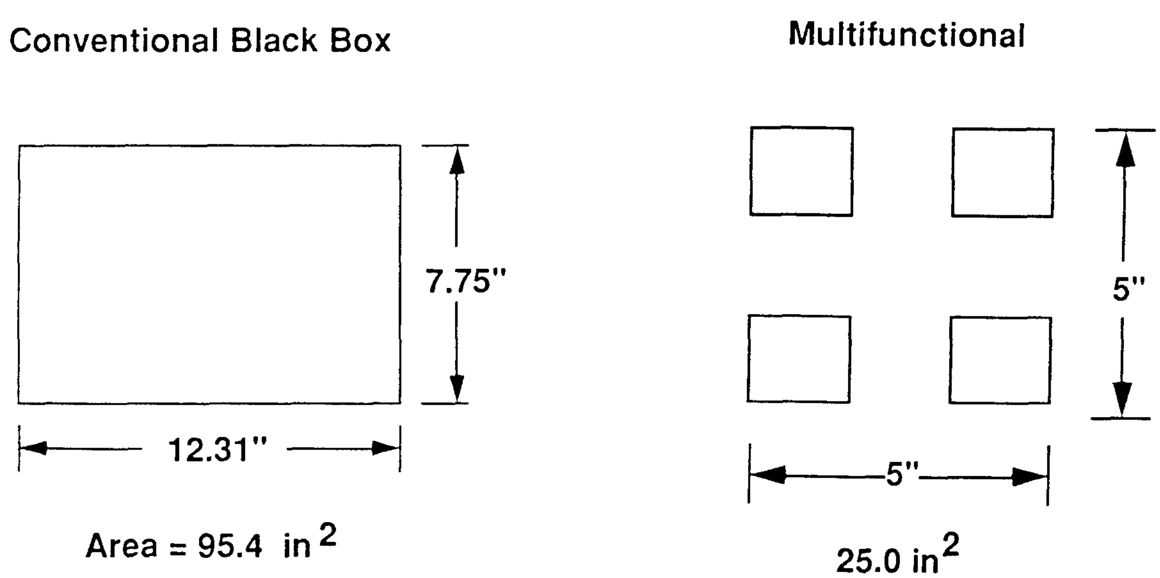


Figure 13. Surface Area

The thermal performance validation consisted of a test involving the actual sandwich panels. Both types of PWB sandwich structures were subjected to a power density of 5 W/in^2 using strip heaters. The panels were instrumented with thermocouples as shown in Figure 14.

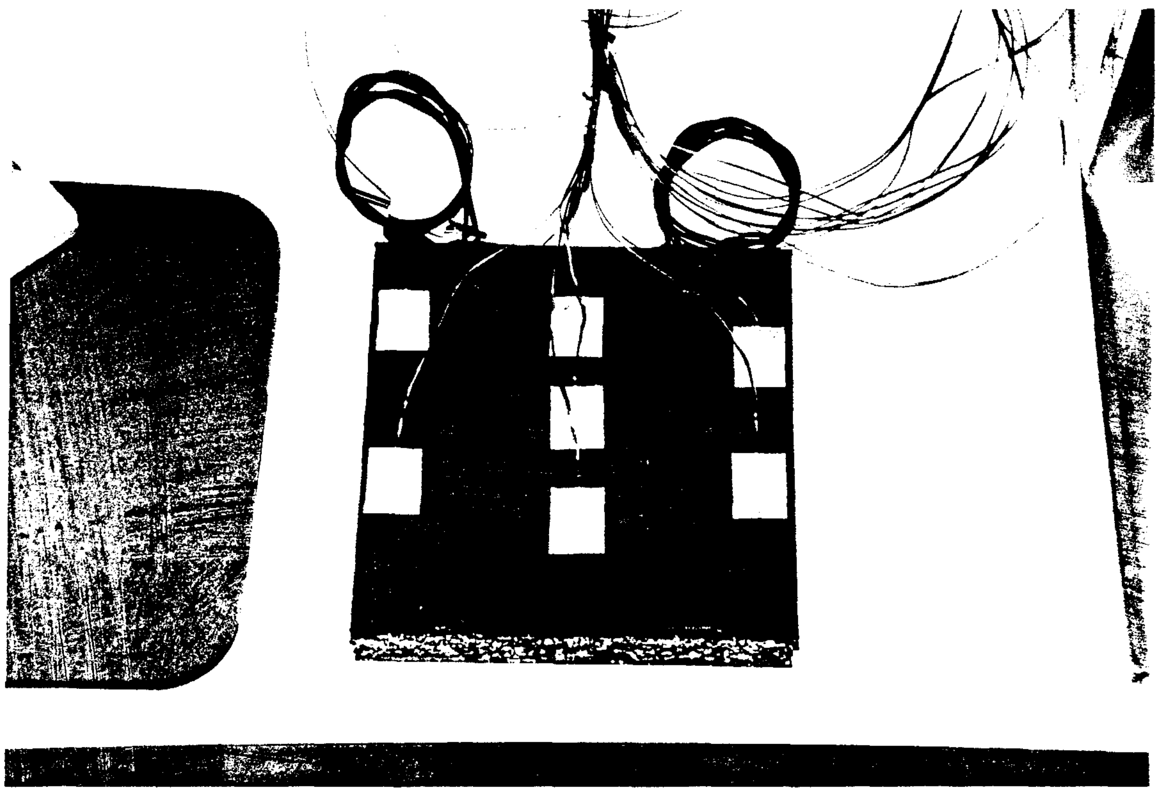


Figure 14. Kevlar-Glass/Cyanate Ester

Sandwich Structure Instrumented with Heaters and Thermocouples

The test articles were placed between two large aluminum blocks to provide a control over radiation and convection losses. The kevlar-glass/cyanate ester sandwich structure is shown in Figures 15 and 16. Figure 17 and 18 show the glass/polyimide sandwich structure before and during testing.

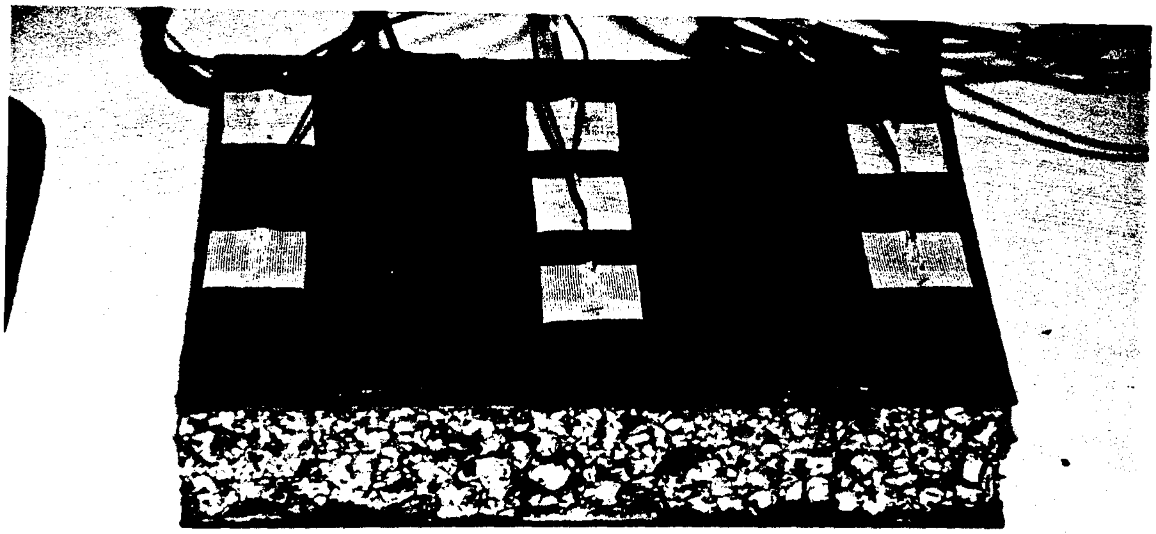


Figure 15 Kevlar Glass/Cyanate Ester Before Test

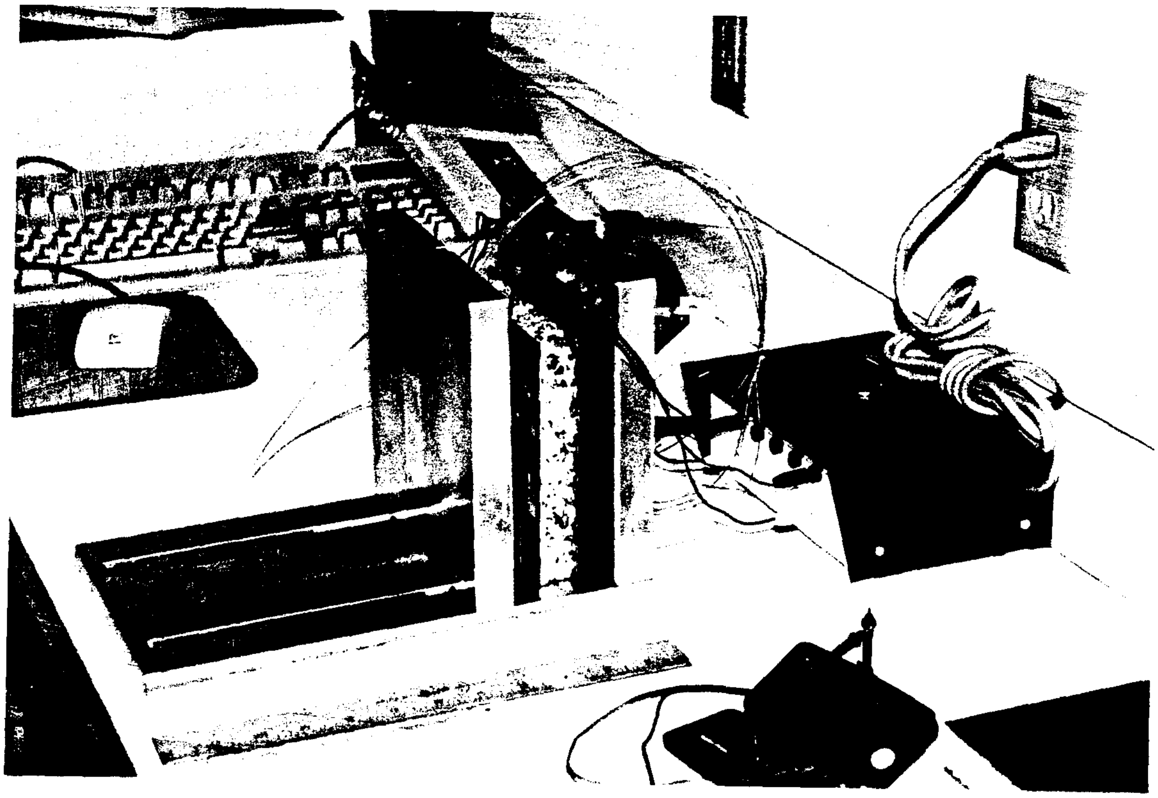


Figure 16 Kevlar Glass/Cyanate Ester in Test Fixture

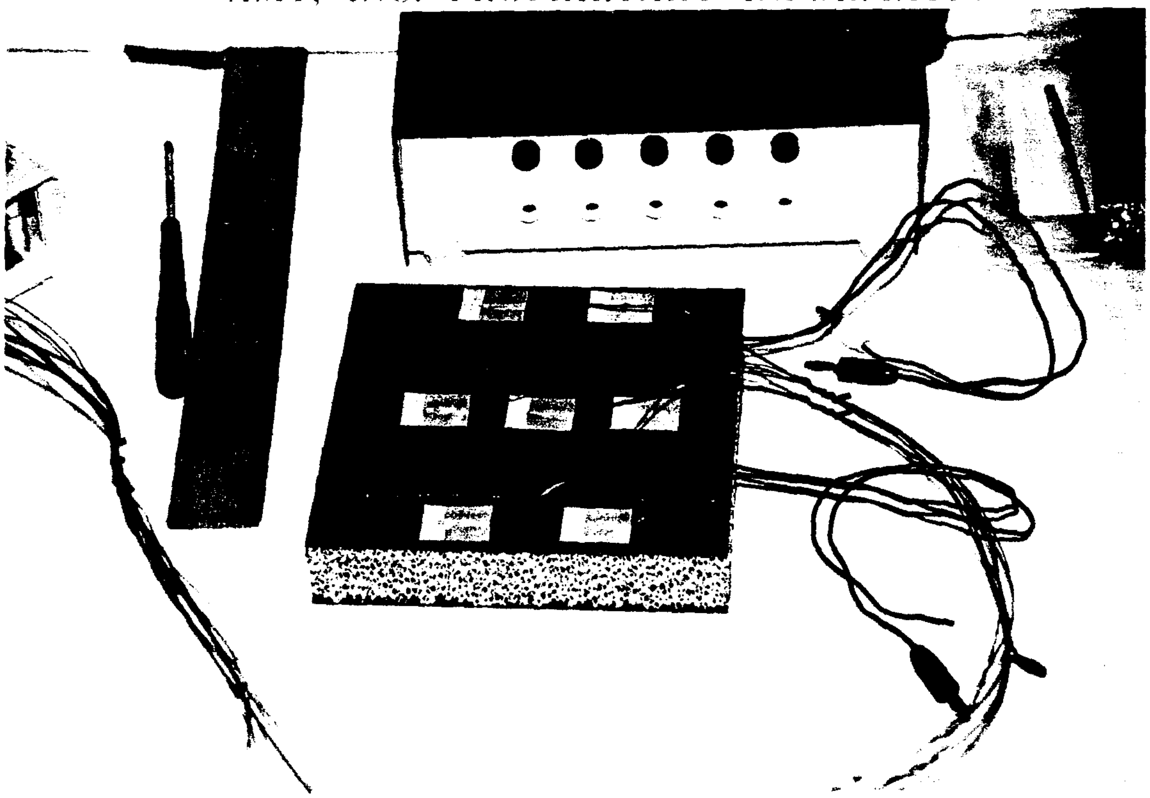


Figure 17. Glass/Polyimide Sandwich Structure Before Test

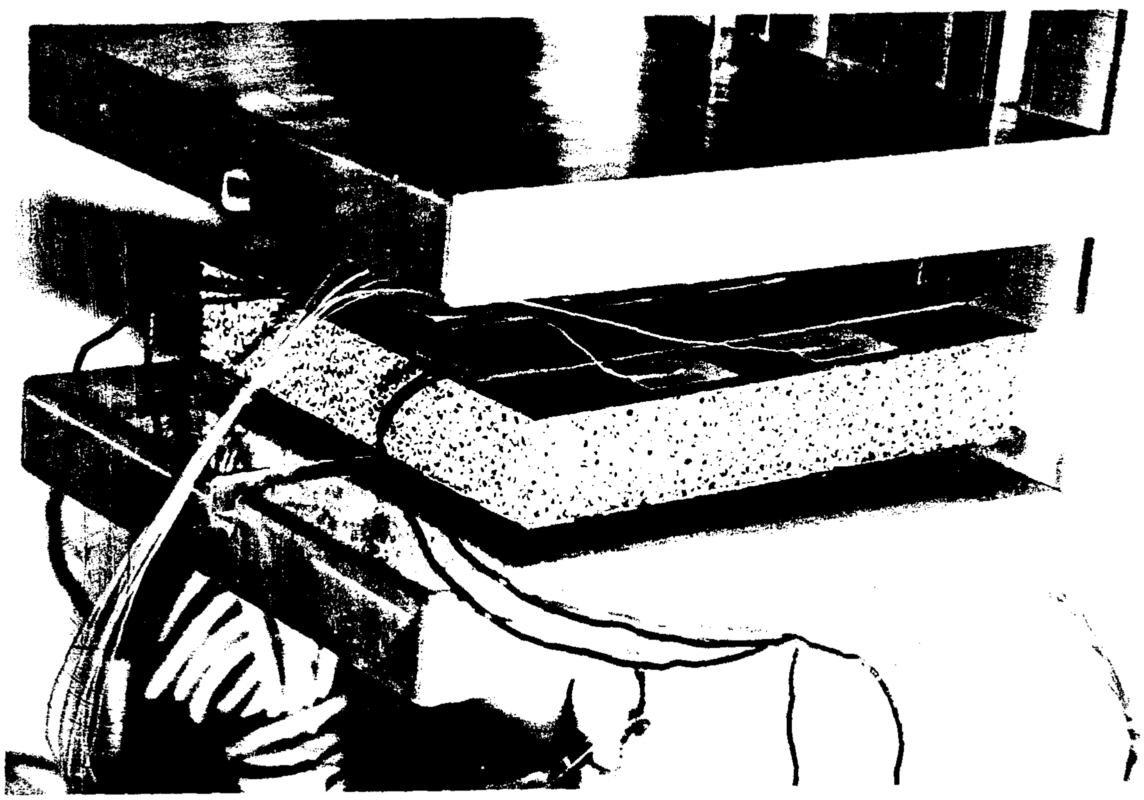
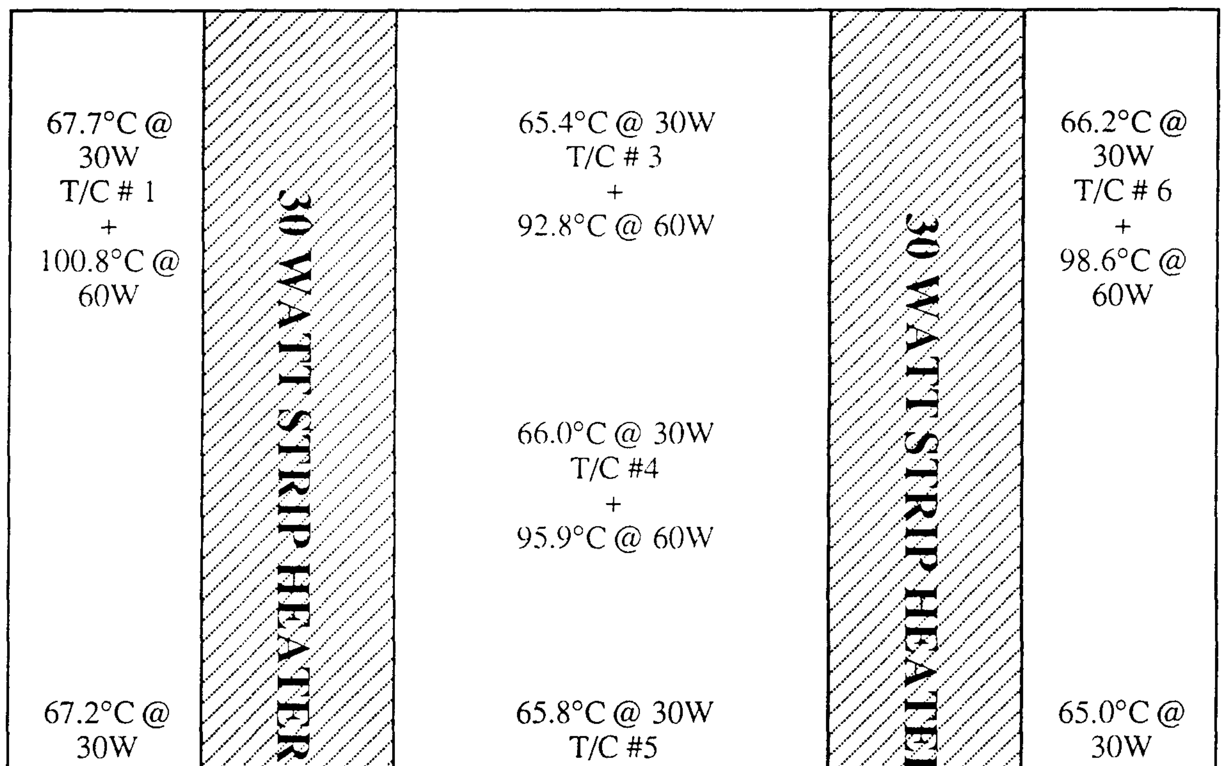


Figure 18. Glass/Polyimide in Test Fixture

The test results at 30 watts and 60 watts of heat are shown for both test articles in Figures 19 (kevlar-glass/cyanate ester) and Figure 20 (glass/polyimide). As shown in the figures, the temperatures and the temperature distribution are approximately the same for both concepts and the values for the temperatures are within a safe operating range for most electronic components. This simulation represents a severe case because the boundaries of the test articles are essentially insulated and the external facesheet panel is radiating to a heatsink that is 273K where a space heatsink can be as low as "0"K. In a full size spacecraft there is more lateral conduction area and the heat will distribute itself over the surface.

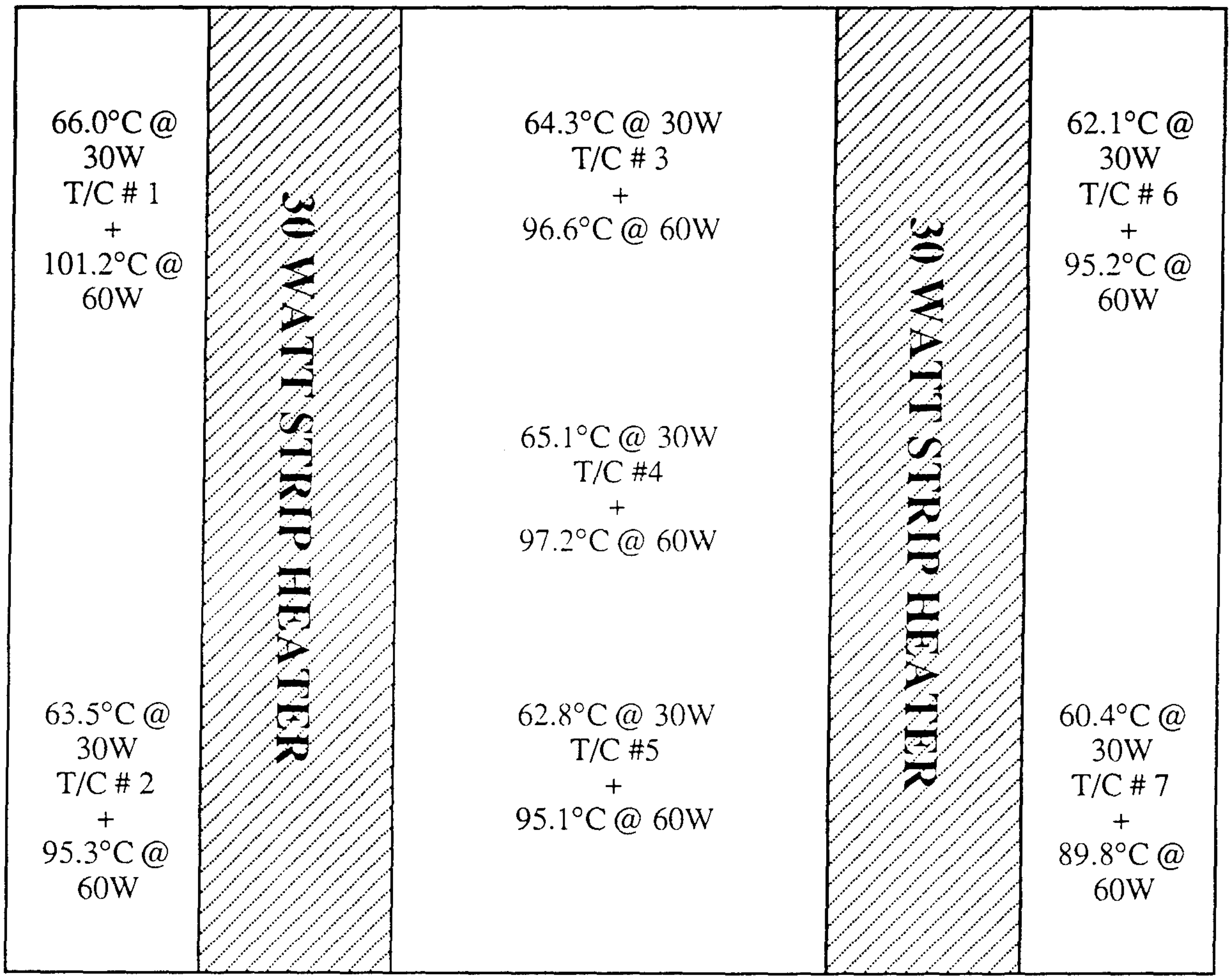
CONSTRUCTION - F.S. 1 KEVLAR/GLASS
CORE ALCAN SIC/AL FOAM F.S.2 K321 1:1



T/C #8 - OPPOSITE T/C #4 BACKSIDE
61.6°C @ 30W
89.3°C @ 60W

Figure 19. Kevlar-Glass/Cyanate Ester Sandwich Structure Temperatures

CONSTRUCTION - F.S. 1 GLASS/POLYIMIDE
CORE ERG AL FOAM
F.S.2 K321 1:1



T/C #8 OPPOSITE T/C #4 BACKSIDE

58.2 @ 30W
91.5 @ 60W

Figure 20. Glass/Polyimide Sandwich Structure Temperatures

4.0 SUMMARY

This project demonstrated the feasibility of developing a highly integrated multifunctional component that would enable MCMs to be mounted directly to the surface of a spacecraft panel. The benefits of this concept over conventional black box technology are summarized as follows:

- > 90% weight savings
- >90% volume savings
- > 70% surface area savings
- Better thermal path for waste heat rejection
- Elimination of extensive amounts of cabling

This concept for packaging is essential if very small spacecraft are going to be developed and deployed. 500 kgs spacecraft that require high levels of electronic data processing cannot be developed using conventional black box technology; the new millenium spacecraft require this technology in order to achieve the mission goals.

The tests shown here provide the basic data that demonstrates that a multifunctional component that has the correct CTE, high thermal conductivity, high stiffness and lightweight can be manufactured. This project is not planned to continue into Phase II however, there are some recommendations that AMT intends to follow up using in-house funds. These are enumerated as follows:

- Use Honeycomb cores with the facesheet materials evaluated
- Determine benefits, if any, of kevlar-glass PWB
- Fabricate > 3 layer PWB
- Populate an actual circuit board

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